C. S. Fazel

Time and Pressure Measurments in the Corona

TIME AND PRESSURE MEASURMENTS IN THE CORONA

BY

CHARLES STEVER FAZEL

A. B. Fairmount College, 1914

M. A. University of Illinois, 1915

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I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY CHARLES STEVER FAZEL

ENTITLED TIME AND PRESSURE MEASUREMENTS IN THE CORONA

BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

Jakob Kunz
In Charge of Thesis

A. P. Carman
Head of Department

Recommendation concurred in*

A. P. Carman
Chas. T. Knipp
F. R. Watson
A. R. Crathorne
G. A. Miller
Joel Stebbins
E. H. Williams

Committee on Final Examination*

*Required for doctor's degree but not for master's

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The gas pressure developed by the corona discharge has been studied by Farwell[1], Kunz[2], Warner[3], Arnold[4], and Tyndall[5]. Warner has shown that the corona pressure developed is proportional to the corona current. He has suggested that there was a true corona pressure distinct from that due to pure thermal effects and as an explanation has suggested the ionization theory. On the other hand, Arnold and Tyndall have contended that the effect was due entirely to the heat developed.

The tube used by Tyndall had a diameter of 2.2 cm. and the wire a diameter of .006 mm., while in Warner's work the tube was 4.5 cm. in diameter and the wire had a diameter of .019 cm. In addition the current used by Tyndall was of the order of magnitude of 10^{-3} amps. (unless there is a misprint in his article as some of his other data would indicate), while Warner used a current of the order of magnitude of 10^{-5} amps. These differences could make the pressure evolution due to heat the predominant factor in one case and the pressure due to the corona in the other.

I THE PRESSURE DISTRIBUTION WITHIN THE TUBE

The pressure difference between the wire and the walls of the tube was measured by a differential gage of the Wahlen type[6]. A special gage was constructed so that the columns over the liquids were as small as possible and the ratio of the cross sectional areas of the tubes was about one to ten.

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1. Proc. A.I.E.E., 33, 717.
2. Phys.Rev., 8, 28.
3. Phys.Rev., 10, 483.
4. Phys.Rev., 9, 93.
5. Phil.Mag., 6, 35, 483.
6. Bull. University of Illinois Eng. Exp. Sta., No.112, p 25, 1919.

[illegible]

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[illegible]

One side of the gage was connected to the outside of the corona tube while the other was attached to a glass tube which could be moved in to the center of the tube. See Fig. 1. The connections from the tube to the gage were kept as short as possible. The gage thus read the difference in pressure between the walls of the tube and the neighborhood of the wire. Considerable difficulty was experienced

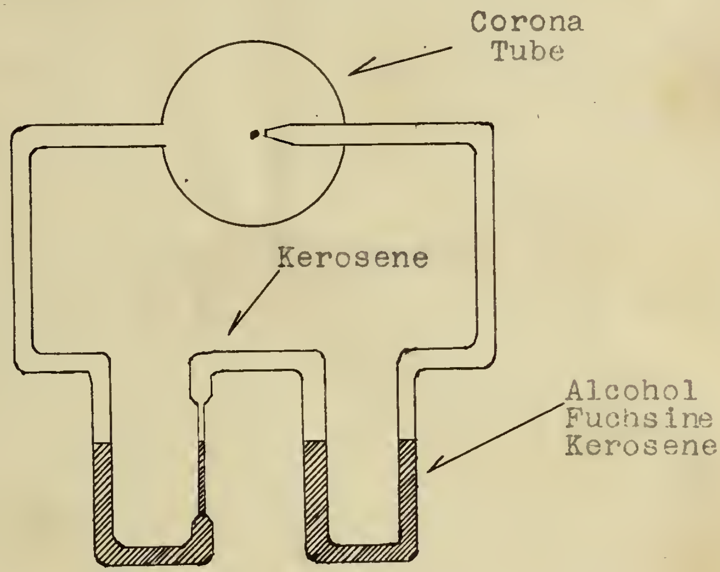

Fig. 1

until the air in the tube was dried very thoroughly by passage through sulphuric acid and calcium chloride. The presence of water vapor lowers the voltage at which an arc will form and tends to decrease the corona pressure difference.

With carefully dried air and the sensitive gage mentioned above a pressure difference between the wire and the tube of about .004 cm. of water was detected at 12000 volts D.C. The walls of the tube were always at the higher pressure whether the wire was positive or negative. The apparatus was not sensitive enough to tell whether there was any difference in the magnitude of the pressure difference when the wire was positive or negative.

Tyndall[7] calculated from the specific ionic velocity that the electric wind should give rise to a pressure difference of .003 cm. of water between the wire and the tube. It would therefore seem that the pressure just measured was due to the ionic motion. This pressure difference will be referred to as the "electric wind pressure" in the same sense that Tyndall uses it.

If this pressure exists it is still difficult to see how such a small pressure could accomplish the cooling which Tyndall attributes to it. The motion of the air due to this small pressure difference lasting for a short time cannot produce very much cooling, specially on account of the small specific heat of air.

In a symetrical tube closed at either end by glass plates and having a wire running its full length the gage did not show any pressure difference along the length of the tube. The difference was measured from the middle to either end and between the two ends. This would seem to show that in the steady state there is not gas circulation along the length of the tube.

II ALTERNATING CURRENT CORONA WITH THE MANOMETRIC FLAME

A corona tube supplied with a sixty cycle alternating potential of twelve thousand volts was connected to a manometric capsule. For photography the gas used for the manometric flame was acetylene. The outside of the corona tube was grounded to eliminate any electrostatic effects. A diagram of the apparatus is shown in Fig. 2.

Using this apparatus a new phenomena was observed. It was found that the flame showed a periodic pressure change of twice the frequency of the impressed electromotive force. By pinching the rubber

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7. Phil.Mag., 35, 264.

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[illegible]

II. [illegible]

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[illegible]

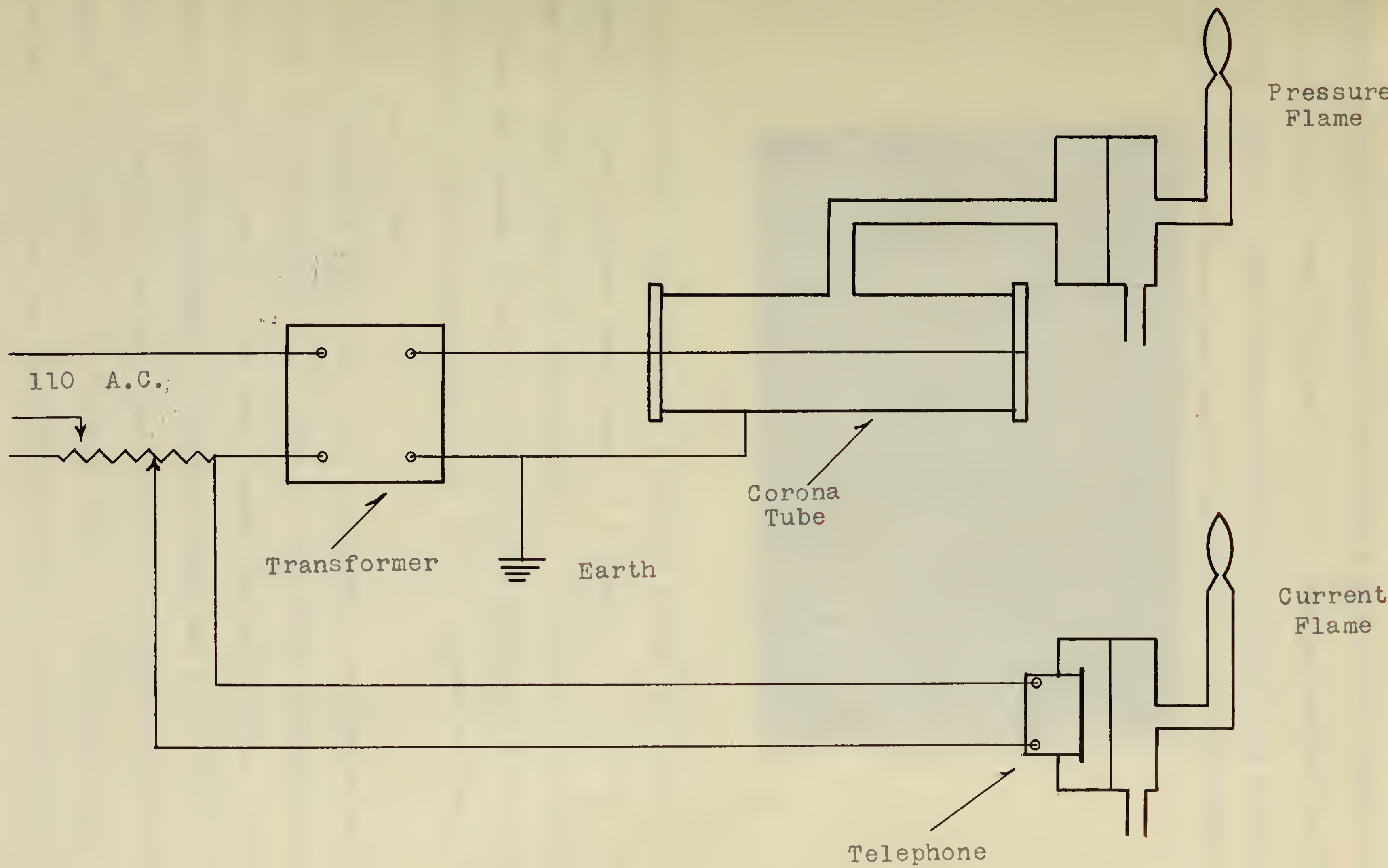
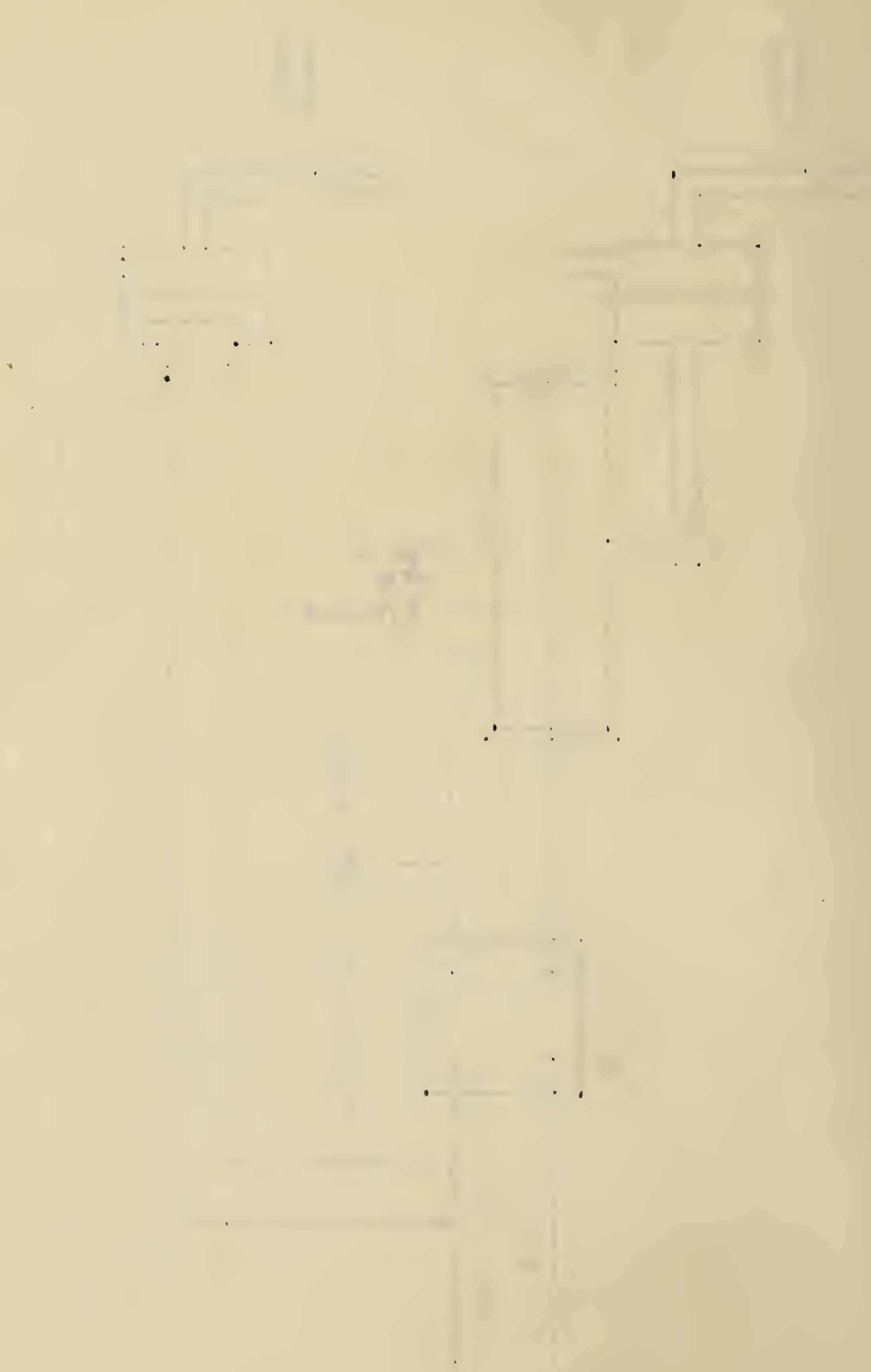

Pressure
Flame
110 A.C.
Transformer
Earth
Corona
Tube
Current
Flame
Telephone

Figure 2.



tube connecting the corona tube with the capsule the vibrations of the flame stopped. Grounding the capsule and other parts of the apparatus produced no effect on the flame. A sample record is shown in Fig. 3. The upper is the pressure while the lower is a manometric flame attached to a telephone which carries part of the same current

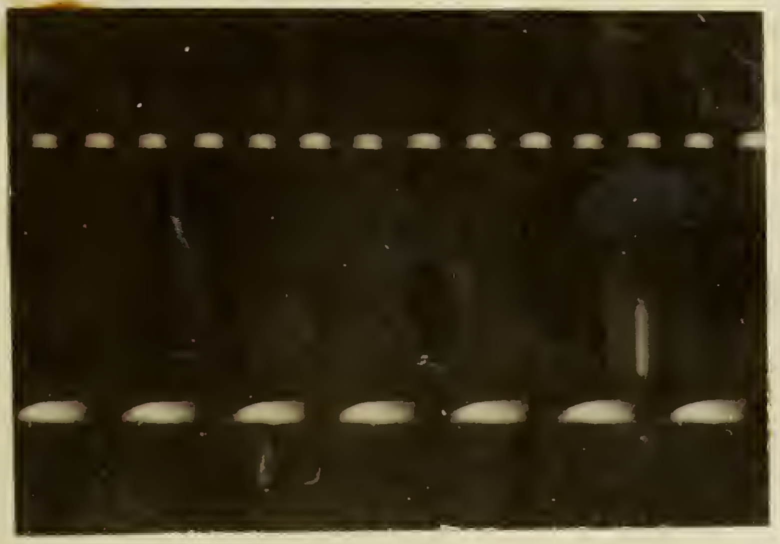


Fig. 3

which actuated the transformer. For this flame each spot of light represents a one hundred twentieth of a second, - for the remainder of the cycle the flame is extinguished. It should be noticed that this pressure change is able to follow a frequency of one hundred and twenty which is much faster than any of the pressure changes observed before in the corona.

It was noticed that the flame was greatly affected on the make and break of the current. In fact it was often extinguished at these times if it was in its most sensitive condition. In order to investigate this phenomena a pressure gage was built which would give readings of pressure rather than change of pressure with the time. The results obtained with this gage will be discussed later (Part IV). The effect of heating the central wire with an alternating current was tried. This was done by putting the 110 volt A.C. through a

resistance and then to the two ends of the central wire of the corona tube. With this arrangement of apparatus the flame did not show any oscillation even though the wattage used was ten or more times that used in the corona.

In case the wire was heated by the alternating current as above and at the same time the corona was put on the tube the flame behaved in exactly the same way as it did when the wire was not heated. That is, the flame showed a periodic pressure of twice the frequency of the impressed electromotive force. This shows that the variations in the pressure depend on having a varying potential difference between the wire and the outside of the tube and not on the temperature of the wire nor in variations of its temperature due to the alternations of the current.

III DIRECT CURRENT CORONA WITH THE MANOMETRIC FLAME

With the same apparatus as used on the alternating current corona, the direct current corona was investigated for an oscillatory pressure. With the direct current on the corona tube no oscillations could be detected except fluctuations with a period of about a second which were likely due to variation of the voltage of the machines. With the spark in series with the tube no oscillations could be detected using the flame and rotating mirror.

IV ALTERNATING CURRENT CORONA WITH THE DIAPHRAGM

The experiments described above with the manometric flame showed that there must be effects on the make and break of the current which could not be shown with the flame. In order to study these effects more fully a quick acting recording pressure gage was constructed.

This consisted of a diaphragm of mica which was placed across the end of a corona tube of which the wire did not run the full length. Attached to this mica plate was a silk thread held taut by a spring. A small mirror was supported by a vertical thread by one edge and the other edge was attached to the horizontal thread. Any motion of the mica diaphragm was thus transmitted to the mirror which gave a deflection of a beam of light. With a mirror one millimeter wide and a distance from mirror to scale of one meter, it was possible to obtain a magnification of two thousand times. The gage as used gave about five centimeters deflections for a pressure of one centimeter of water. Mica diaphragms having a thickness of .135 mm. and .070 mm. and a celluloid diaphragm having a thickness of .095 mm. were used. The natural period of the gage as used in most of the experiments was in the neighborhood of 700 vibrations per second. The current in the primary was recorded by an oscillograph. A diagram of the apparatus is shown in Fig.4.

Using such a gage, Fig.5 shows the increase in pressure in a corona tube when an alternating current of sixty cycles is thrown on. The voltage is about nine thousand volts at the peak.

The halo on the rising line is due to diffraction of the beam of light at the slit. The lower curve is the sixty cycle wave representing the current. The record begins about one fourth of the distance from the right hand side and reads from left to right. There is some overlapping due to the shutter not being closed quickly enough.

It is evident that there are present the oscillations shown by the flame having half the period of the impressed electromotive force, but these are superimposed on a gradually increasing pressure which

reaches a constant value in about a second and a half. There are two distinct types of pressure here, one which is able to follow variations of one hundred and twenty cycles per second, and another which requires more than a second to reach its value. The rapid pressure variations are of such a large value that they cannot be the electric wind pressure. The "electric wind" pressure should have a magnitude of about .005 cm. of water while the pressure here is more than .3 cm. of water.

Fig.6 shows three records in which an attempt was made to study in greater detail the steady state of oscillation reached at the end of Fig.5. This was studied by the use of a thinner diaphragm and greater magnification by decreasing the length of the mirror and increasing the distance to the scale. In each the lower curve is the sixty cycle current for time. It has been found necessary to retouch the films for printing. The upper record of the three is believed to be the best as it is the one which agrees with the manometric flame records and seems most free from distortion. The other two show the presence of some other wave differing in phase and amplitude from the pressure oscillation.

The variations in pressure which follow the breaking of the primary current of the transformer were studied and Fig.7 shows the result. There is a slow dying away of the pressure which corresponds to the slow increase shown in Fig.5. However, there is a new phenomena as the oscillations persist with their original frequency and die out very slowly. These cannot be due to the natural frequency of the diaphragm or measuring system on account of the difference in frequency, nor could it be the natural frequency of the electrical system as it would be in the millions of oscillations per second.

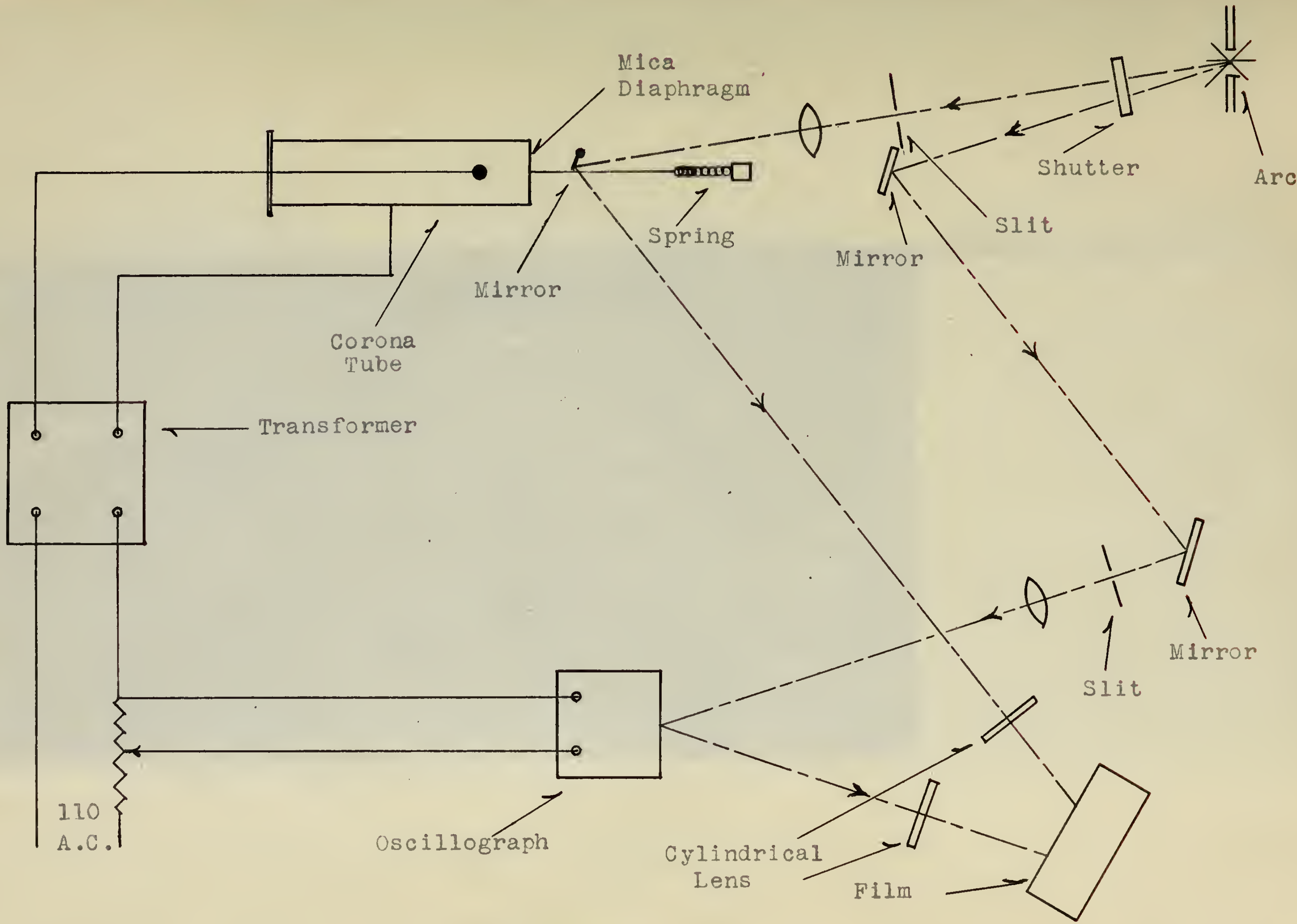
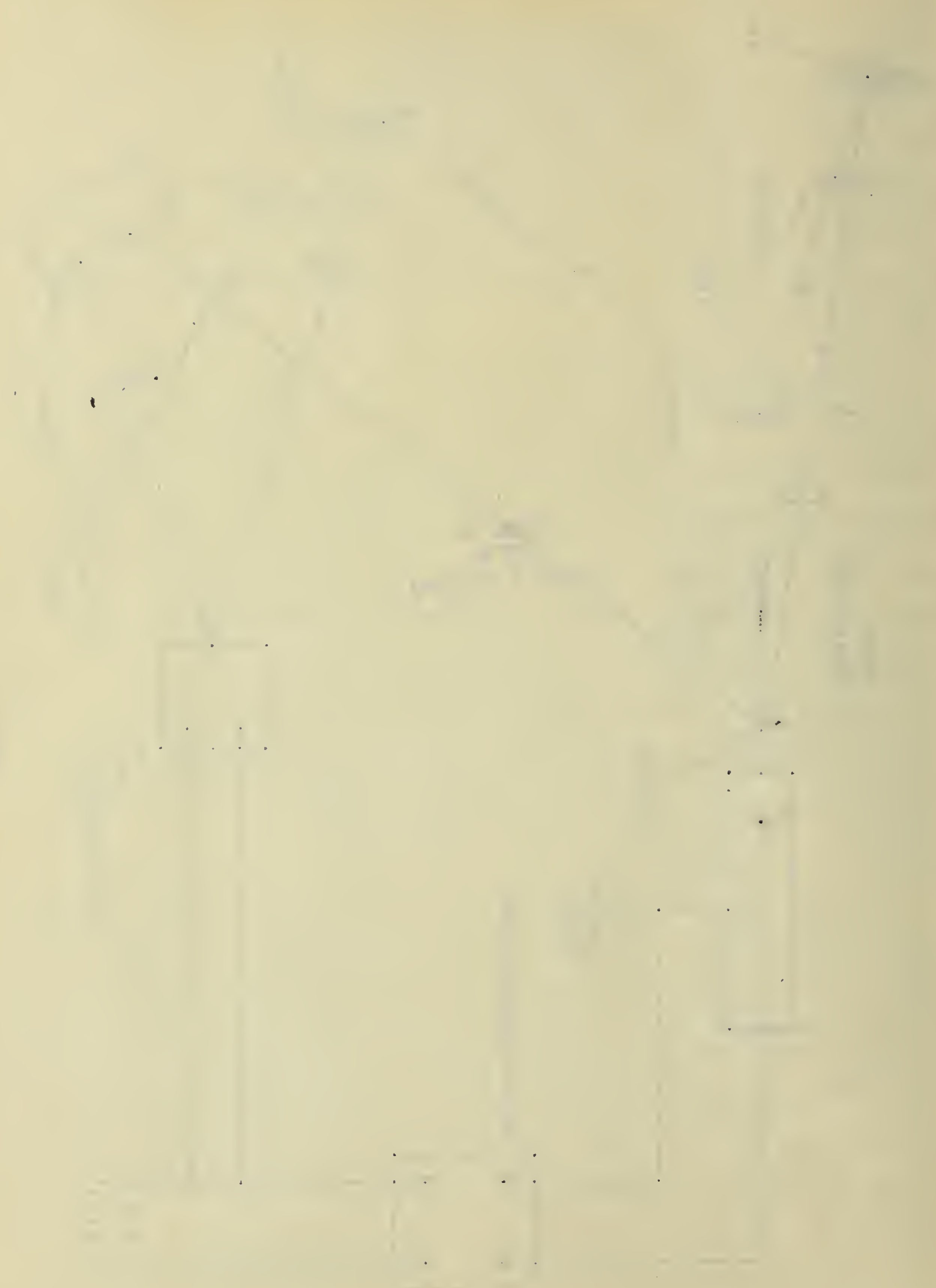

Mica
Diaphragm
Arc
Shutter
Slit
Mirror
Spring
Mirror
Corona
Tube
Transformer
Mirror
Slit
110
A.C.
Oscillograph
Cylindrical
Lens
Film

Figure 4.



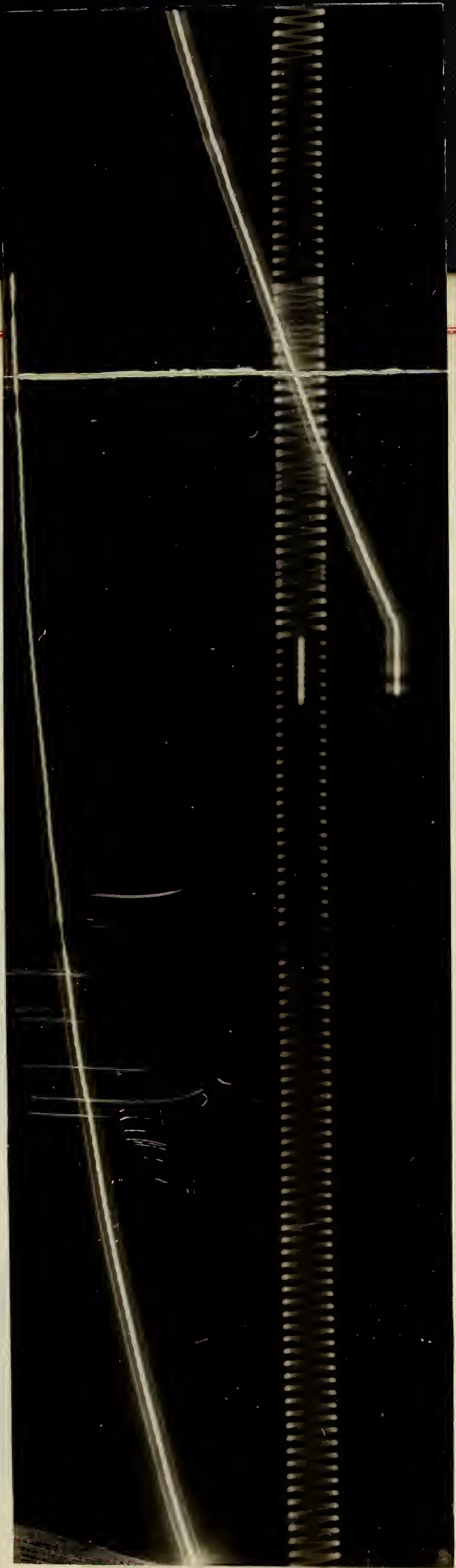


Figure 5.

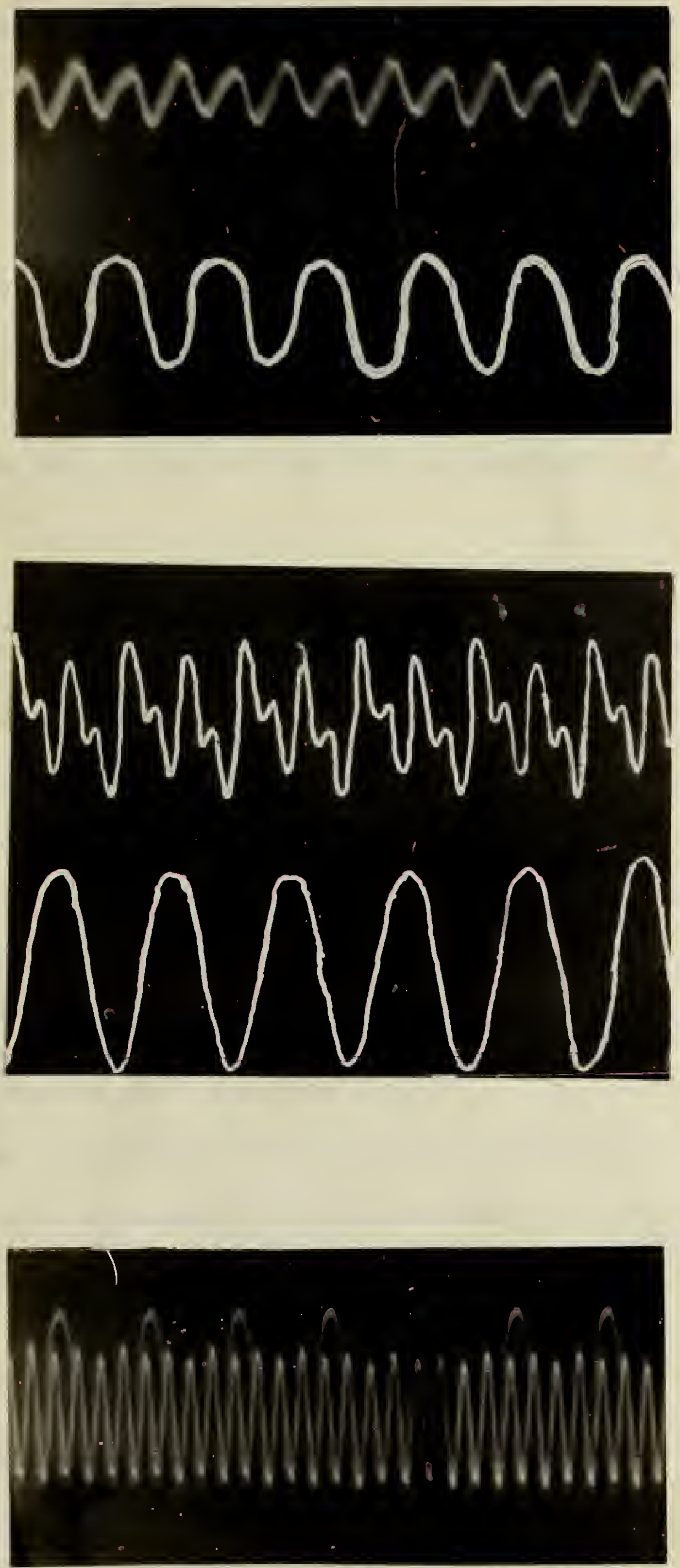


Figure 6.

V DIRECT CURRENT CORONA WITH THE DIAPHRAGM

Records were also taken of the pressure increase in the direct current corona for comparison with the alternating. There was no suggestion of oscillation in the direct current records. Fig.8 was drawn showing a characteristic pressure increase curve for the direct and alternating current corona. These curves were drawn from measurements of two photographic records which were taken under as nearly the same conditions as possible. They are drawn together so as to obtain the same time scale for comparison.

VI HEAT EFFECTS IN THE CORONA TUBE

In order to study the effect of heat alone on the pressure development an alternating current was sent through the central wire and the increase of pressure observed. It was found that this pressure increase was so slow that it could not be recorded on a photographic film with the apparatus at hand and so the results were obtained by visual observation. It was found possible to reproduce these observations within half a per cent at the upper values and so the method was considered satisfactory.

Fig.9 shows the curves for several different currents through the wire. It will be seen that the maxima are not reached until the wire has been heated for more than twenty seconds, while Fig. 8 showed that in the direct and alternating current corona the maximum is reached in less than two seconds. Further, the time required to reach the maximum does not depend upon the current to any marked extent. The maximum pressure reached depends on the current through the wire as would be expected. There is a marked difference in form of curves in Fig.9 from those of Fig.8. There would be no difficulty

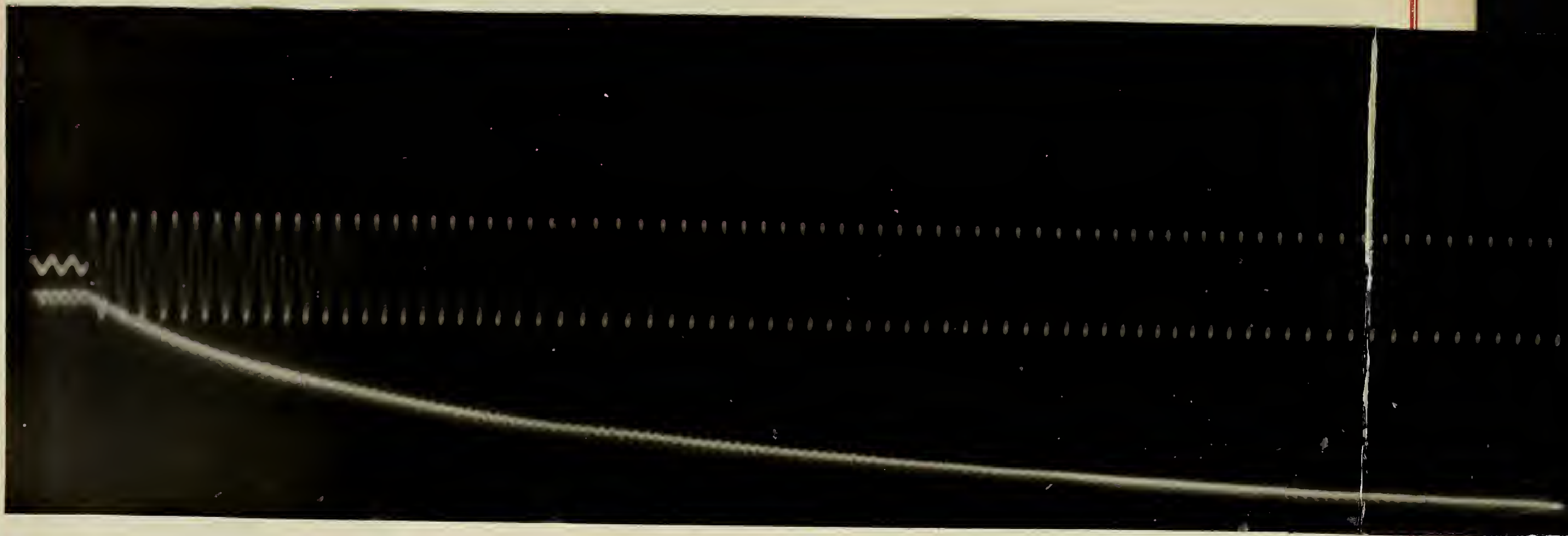
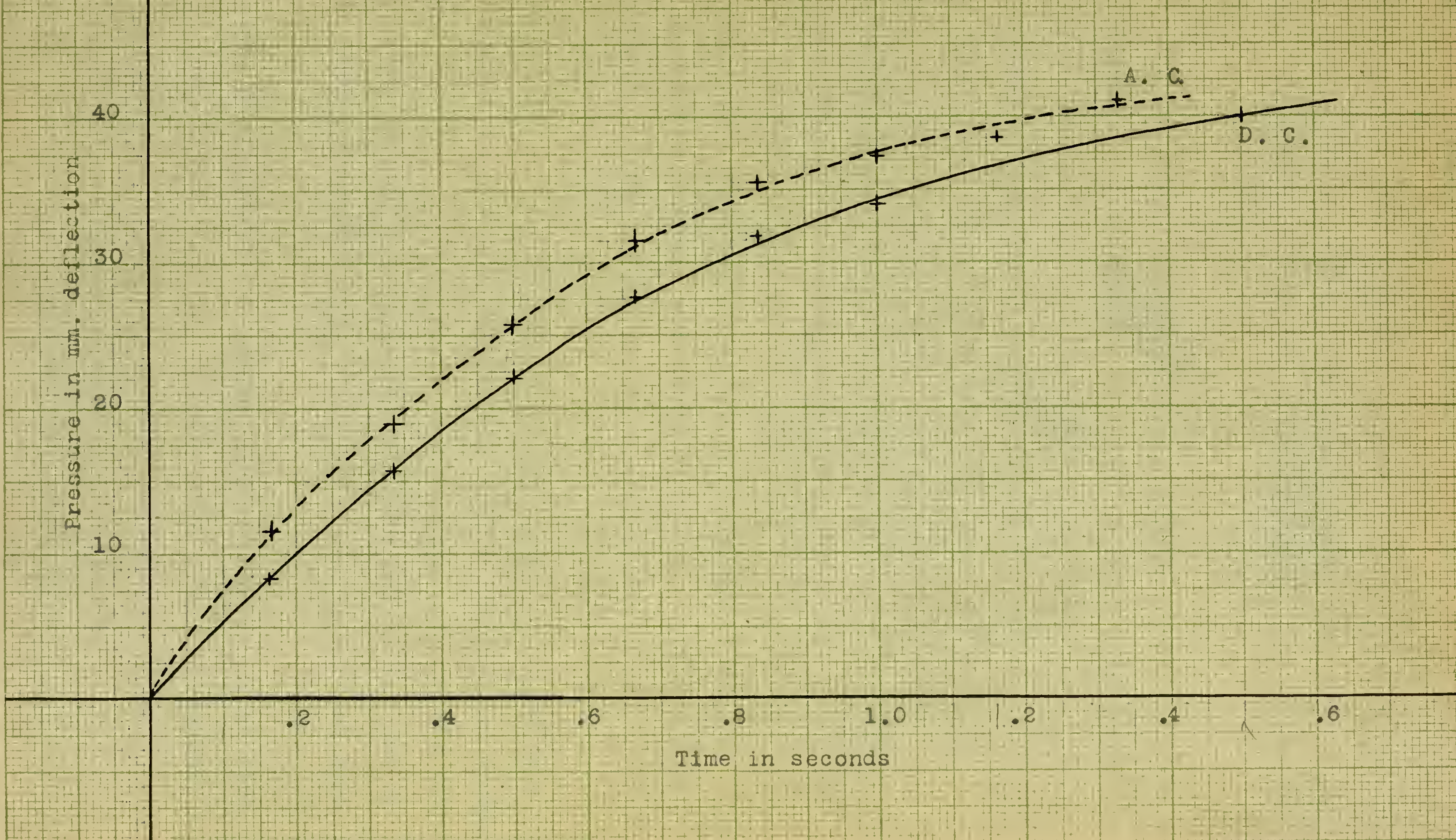


Figure 7.

Figure 8.



A. C.
D. C.
40
30
20
10
Pressure in mm. deflection
.2
.4
.6
.8
1.0
.2
.4
.6
Time in seconds

in distinguishing this type of pressure from the very rapid type shown in Fig.3 and Fig.5. It is evident that the pressure due to the heat evolved in this experiment and in the pressure due to the corona is different.

VII RELATION BETWEEN HEAT AND CORONA

Tyndall describes an experiment in which he had a tube with a wire heated by a current such as that used in the preceding experiments, and the heated wire caused a development of pressure similar to that just described. After the pressure had reached a steady value he threw on the corona and observed a pressure decrease. A similar experiment was performed recording the slow part by visual observations and the pressure changes when the corona was first put on by means of the recording pressure gage. The record of the pressure changes when the corona was first put on is shown in Fig.10. The results of the whole experiment are shown in Fig.11. The oscillations do not appear in Fig.10 due to the condensation of the time scale.

It is seen that as soon as the corona is thrown on there is a very quick increase in pressure followed by a slow decrease in pressure to another constant pressure below the original. Tyndall's failure to observe the initial increase may have been due to the use of a rather slow acting pressure gage, or to the relation between heat and corona.

A study was then made of the maximum excursions on either side of the steady state by varying the voltage across the transformer. A number of records similar to Fig.11 were made and the value of the sharp peak reached after the corona was thrown on was plotted above the axis in Fig.12 with the voltage of the transformer as abscissa.

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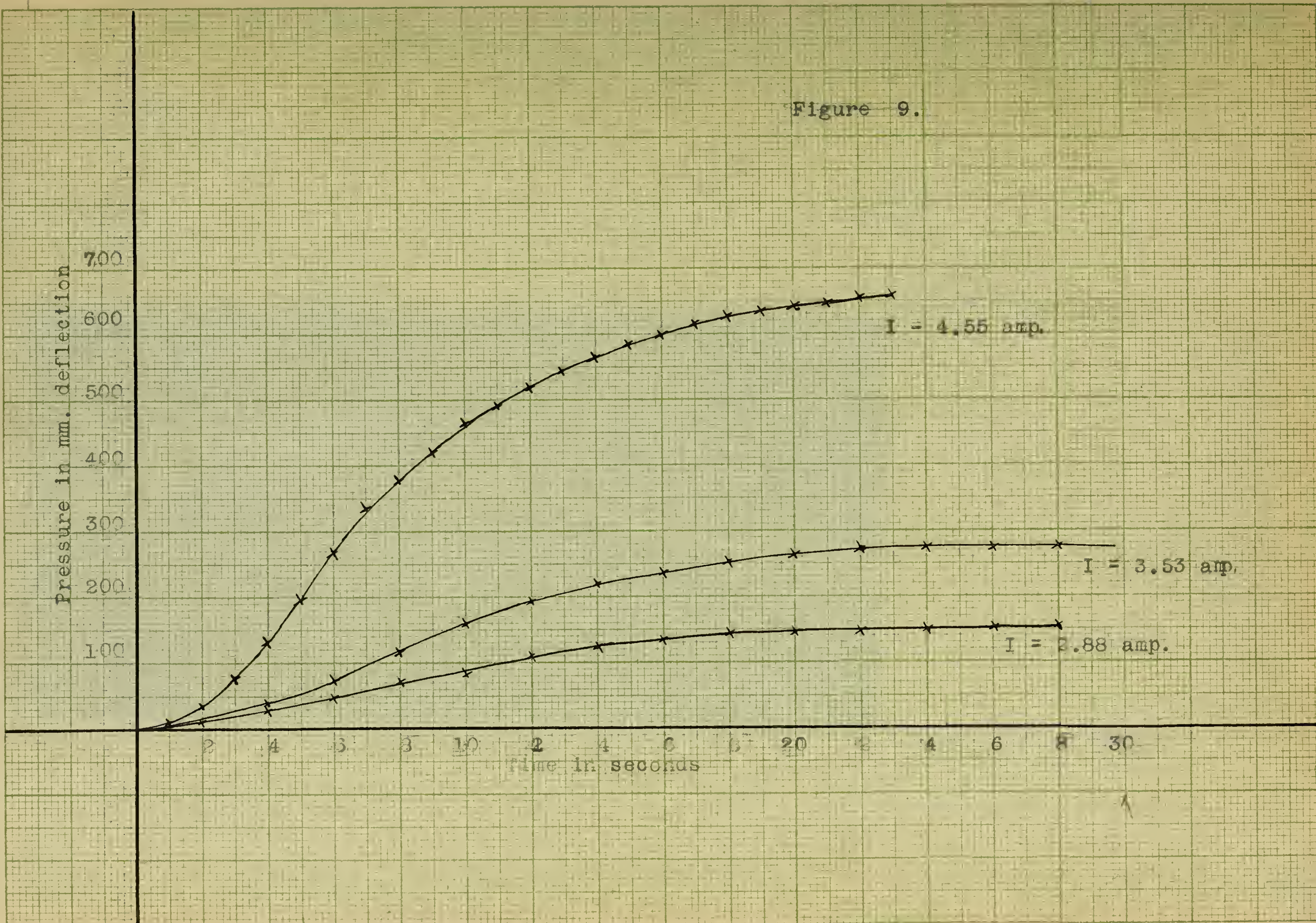

Pressure in mm. deflection
700
600
500
400
300
200
100
Time in seconds
10
20
30
I = 4.55 amp.
I = 3.53 amp.
I = 2.88 amp.

Figure 9.

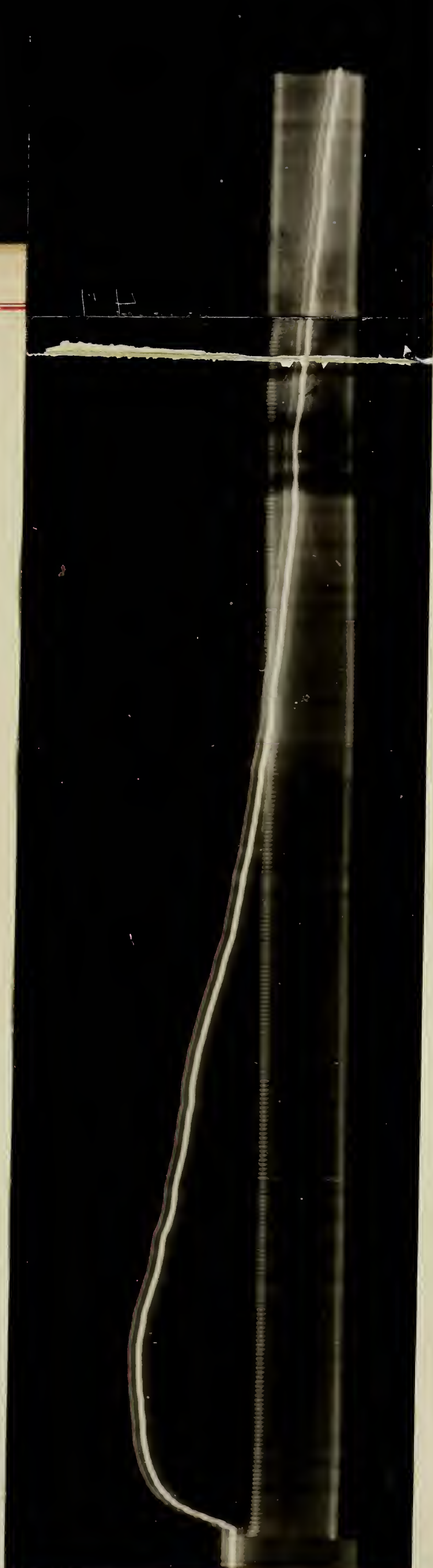
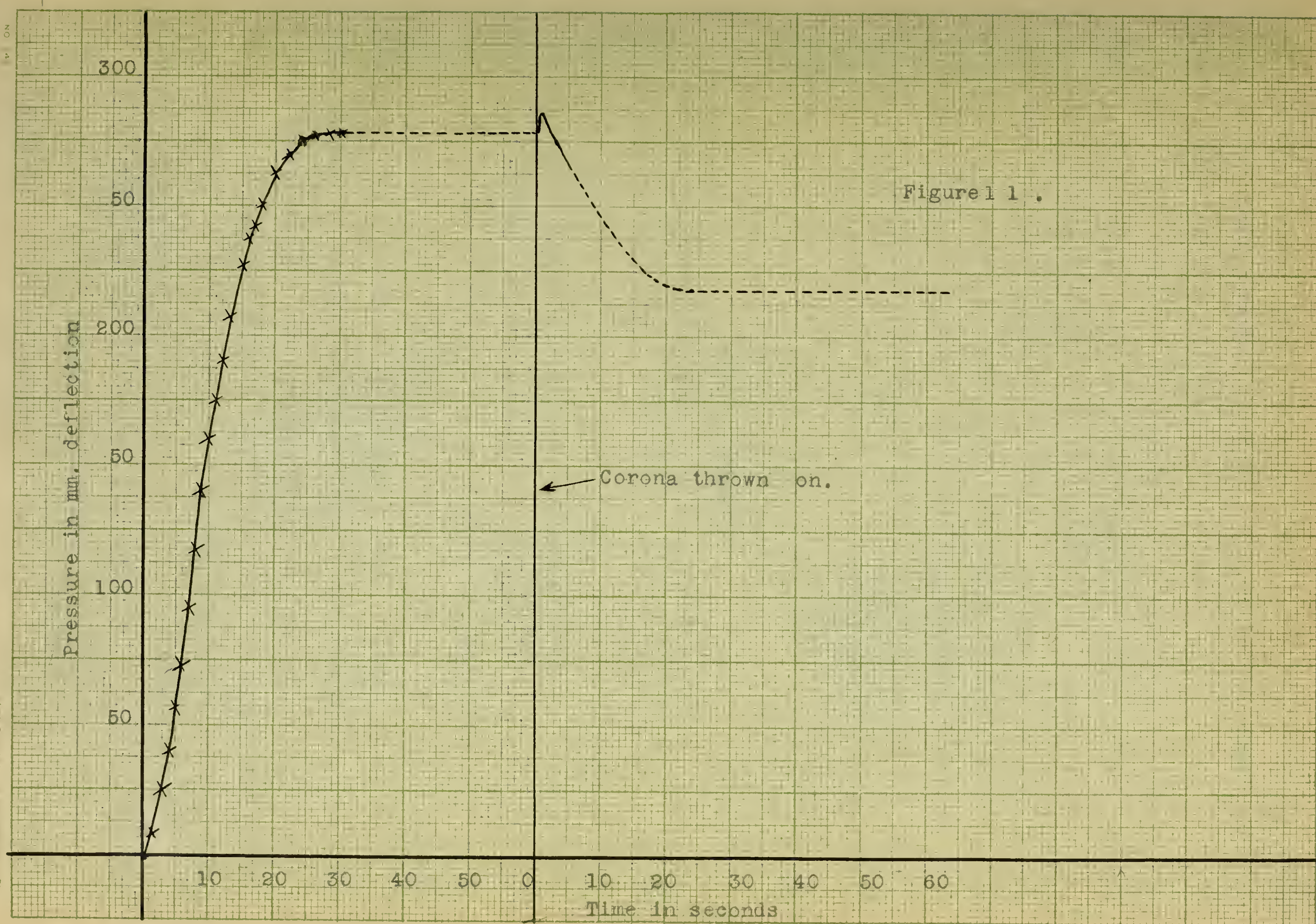


Figure 10



Pressure in mm. deflection
300
50
200
50
100
50
10
20
30
40
50
0
10
20
30
40
50
60
Time in seconds
Corona thrown on.

Figure 1 .

Likewise the final pressure reached at the end of the experiment was plotted below the axis in Fig.12.

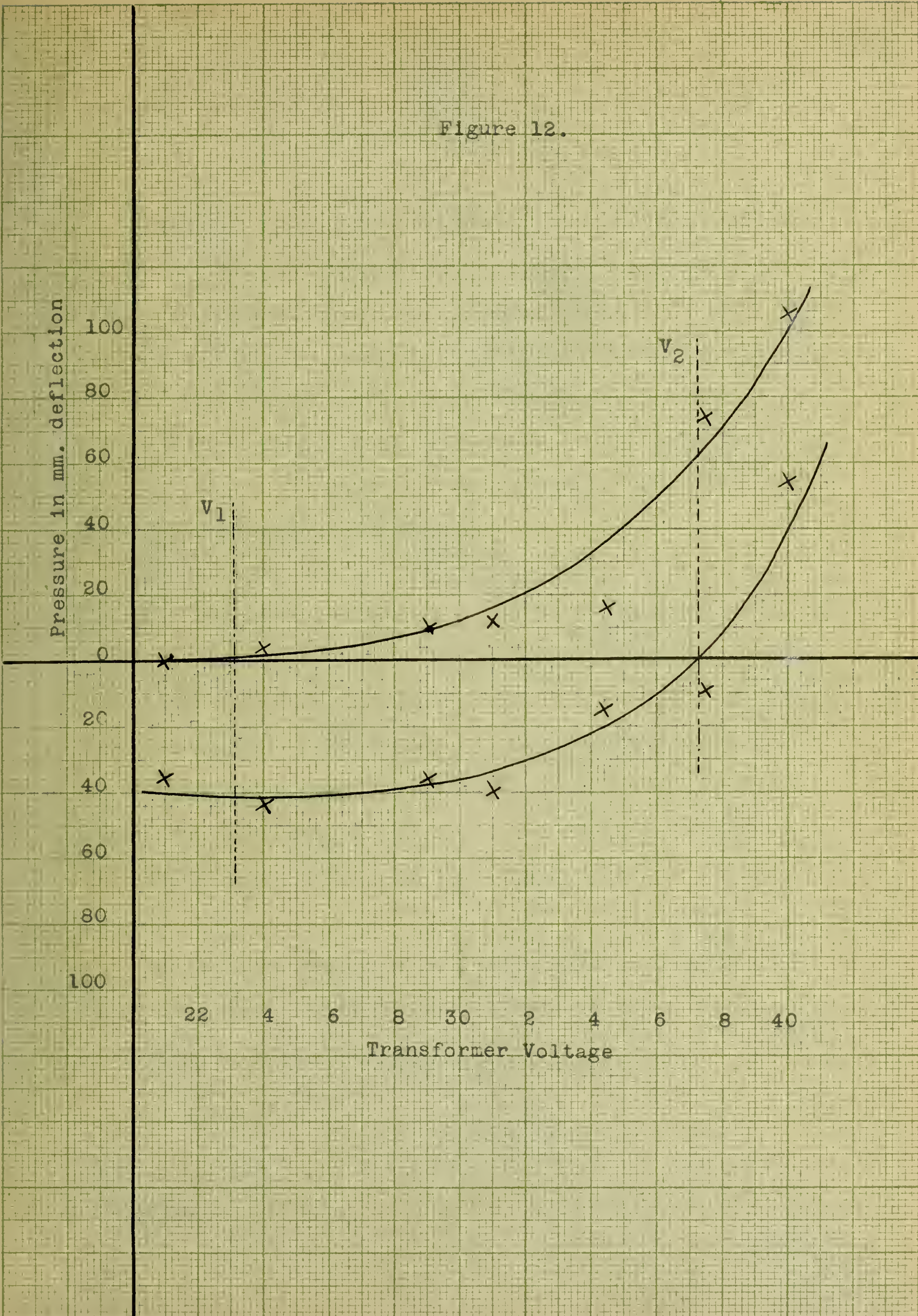
From these curves it is seen that it is possible to find a voltage, V_1, below which there is a decrease in pressure without any appreciable initial increase. It is possible that Tyndall's experiments were conducted below this voltage. Between the voltage V_1 and V_2 there is an increase in pressure followed by a decrease to a value below the original pressure. Above the voltage V_2 the pressure increase is followed by a decrease but to a value above the original pressure. This shows that there is a superposition of several effects.

VIII SUMMARY

The gas pressure phenomena in the alternating and direct current corona have been studied. It has been found that there are four of these phenomena in the corona tube: first, there is a pressure difference which appears between the tube and wire of the order of magnitude of .005 cm. of water; second, a pressure of the order of magnitude of .3 cm. of water which is able to follow the variations of one hundred and twenty cycles per second. Third, there is a pressure which develops in about a second and a half. This has been carefully studied by Warner who showed that it was proportional to the current provided that the heating effect was kept small so that it would not obscure the effect. Fourth, a pressure due to the Joule heating which is much slower than any mentioned above and must depend on the product of the current and the electromotive force.

The author desires to express his thanks to Dr. Jakob Kunz for advice and aid throughout the experiments and to Professor A.P. Carman for facilities furnished.

Figure 12.



Pressure in mm. deflection
100
80
60
40
20
0
20
40
60
80
100
V_1
V_2
22
4
6
8
30
2
4
6
8
40
Transformer Voltage

VITA

Charles Stever Fazel completed his secondary training at the Wichita High School, of Wichita, Kansas, in 1910. He entered Fairmount College, Wichita, Kansas, the following fall and received from it, in 1914, the degree of A.B. cum laude. In 1914 he entered the University of Illinois as a graduate student where he remained until August, 1917. He again took up residence as a graduate student in September, 1919.

He has held the following positions: Scholar in Physics, University of Illinois, 1914-15; Assistant in Physics, University of Illinois, 1915-17; Instructor in Artillery Cooperation, United States Army School of Military Aeronautics, and Second Lieutenant, United States Army School of Military Aeronautics, 1917-19; Assistant Physicist, U.S. Bureau of Standards, January to September, 1919; Assistant in Physics, University of Illinois, 1919-20.

He has published the following paper: "The Heat of Vaporization and Work of Ionization", Physical Review, N.S. Vol.XV, No.3, page 232, 1920.